pin **49** on piston **47** to retract until it reaches the default position (whereat it will not apply significant pressure to the skin).

[0055] Another embodiment of pressure-driven stimulus points **17** in array **15** is shown at **FIG. 7**. In this embodiment pins may be dispensed with entirely, working fluid (in this case, preferably a gas such as air) passing through openings **53** in matrix **19** shaped to direct flow and increase velocity (i.e., jets), the air flow directly impacting the user's skin. The low density of the gas and the presence of a lateral escape path means that high pressure of the gas and considerable volume flow are needed to produce a reasonably strong sensation. The pressure and volume needed is strongly dependent upon the spacing between matrix **19** of array **15** and the skin, and this spacing is partly dependent on the amount and pattern of pressure applied. A large volume of airflow through constricted openings **53** may also result in significant noise which must be muffled in the particular application. If liquid is utilized as the working fluid, such would require additional systems (fluid recovery and control, primarily, as shown below).

[0056] As further shown in **FIG. 7**, either of the above-described embodiments of the pressure-driven stimulus points **17** in array **15**, and alternatively in addition thereto, could be deployed with flexible stretched membrane **57** interposed between stimulus points **17** and the user's skin. The flexible membrane is anchored at the edges of array **15**, but is otherwise resiliently allowed to conform to a shape that balances the pressure of the stimulus and the pressure resulting from the resilience of the skin. This approach has the effect of smoothing out the effects of multiple stimulus points **17** over a wider area, and also directing the flow of spent working fluid, which in the case of liquid will simplify fluid recovery. When gas is used as a working fluid, this approach results in reduction in the pressure and flow rate needed for a given level of stimulus. Care in material selection and tautness of application will ensure that the spatial resolution of display array **15** is maintained at an acceptably high level.

[0057] Matrix **19** determines spacing of stimulus points **17** and also the surface over which the stimulus points will be applied, and a wide variety of materials for such purpose could be conceived and utilized. A flat matrix is simplest to implement, and is the most useful for representing a textured flat surface (for example, an accessibility application where the intention is to emulate the functionality of an extended flat tactile display). A curved matrix conforming more closely to the surface of a finger, for example, will cover a greater total area of the body location than a flat matrix providing the ability to portray a wider variety of tactile sensations. This capability would be particularly useful with data glove **23**. In the design of a curved matrix, there is likely some benefit in choosing a nonuniform distribution and corresponding size of stimulus points, with the greatest concentration contacting the part of the body location (e.g., finger) that would be most likely to be contacted when touching a surface. Finally, a flexible matrix would permit dynamic wrapping of display array **15** around the body location, with the possibility of a tighter fit and more realistic sensations. In such case, flexing of the matrix must be accounted for.

[0058] Alternative approaches in design of the various elements of the apparatus of this invention may of course be utilized, particularly those related to alternate driving mechanisms (i.e., actuators such as the computer controlled valve array **29** shown hereinabove) for small scanned graphic displays wherein multiple stimulus points are controlled per actuator.

[0059] For example, the refresh rate of display **15** required depends on the level of performance needed (in terms of degree of realism and maximum lateral speed to be represented), and can be in the range of tens to hundreds of frames per second. A single stimulus generator (such as a computer controlled valve) with a bandwidth of tens of kHz or higher could be scanned across all of the tactile stimulus points **17** of display array **15**. A more practical approach would be to use sufficient actuators to drive one row of stimulus points **17** in array **15** at a time, and to scan these actuators across all of the columns of the display array **15** (note that the distinction between a row and column is arbitrary in this context). In this manner, a twenty by twenty array as shown in **FIG. 1** for example, could be driven using twenty actuators. Bandwidth of each actuator would generally be in the hundreds of Hz to kHz range. If display array **15** is built into a tracking device, a considerably larger volume is acceptable.

[0060] The direction of column scanning across the array can be always in one direction or back and forth (active both directions). Intensity modulation of stimulus points **17** can be done by varying the force applied at a stimulus point, varying the duty cycle of the stimulus at each stimulus point during each frame (i.e., scan), or by applying pseudorandom patterns of stimulus to the array that vary in successive frames, such that on the average every stimulus point **17** is driven the correct percentage of the time to give the stimulus intensity desired for that point **17**.

[0061] Examples of driving methods that meet the requirements of this approach are high speed valves or injectors with pressurized working fluid, acoustic generators and the like. High speed valves or injectors put out bursts of working fluid representing the stimulus to each of a number of stimulus points **17** at array **15**. Fluid must be diverted into separate channels by one of several scanning methods to permit separate control of individual stimulus points **17**. The drivers must be capable of much faster operation (e.g., ten to twenty times faster) than the microvalves driving individual stimulus points in the preferred implementation described above. Such devices, however, are presently known and commercially available.

[0062] Acoustic generators, such as voice coils and piezoelectric tweeters, produce modulated acoustic energy. The necessary driving frequency for a row-scanned fingertip tactile display array **15** is within the frequency range of human hearing. Thus, stimulus energy could be generated by acoustic devices, and then distributed and transmitted via acoustic wave guides to the tactile stimulus points as transverse, rotational, or longitudinal shock waves. If desired, mechanical transducers (such as high frequency one-way valves that convert longitudinal pressure waves in a working fluid into bursts of fluid for transfer into a pressure chamber) at tactile stimulus points **17** can convert the acoustic signals into pressure-based stimulus, corresponding to the stimulus type described hereinabove.

[0063] A number of scanning methods can be used in conjunction with such alternative driving methods to allow